

Chapter 8

Operations and Maintenance

8-1. Introduction

This chapter presents guidance for performing appropriate operation, maintenance and monitoring (OM&M) for an SVE/BV system after the start-up and commissioning phases described in Chapter 7 are complete. Since initial OM&M activities are conducted during the start-up phase, Chapter 7 should also be referred to when planning this phase of remediation

8-2. O&M Strategy

This section presents an overview of a typical OM&M strategy, including operational guidelines, monitoring parameters, and system modification considerations. The basic monitoring protocol should have already been set when planning the start-up procedures discussed in Chapter 7. The OM&M plan may also take the form of a long term monitoring plan (LTM), and sampling and analysis plan (SAP). Table 8-1 is a troubleshooting guide for major operational problems of SVE/BV systems. The risks of encountering the operational problems listed in Table 8-1 can be reduced by proper implementation of the site characterization, bench-scale study, and pilot study phases of the project; however, the uncertainties cannot be totally eliminated due to the uncertainty inherent in employing in situ technologies. Operational problems, such as those listed in Table 8-1 may be encountered despite the best efforts to avoid them. Therefore, the design should be as flexible as possible and the OM&M plan should include contingencies for possible operational problems.

a. The system OM&M plan is typically developed based on three areas of consideration: project needs, site considerations, and system design. The plan then generally addresses the routine procedures for operation, maintenance, sampling, analysis, and system modification, as well as nonroutine activities such as troubleshooting and shutdown. It is important that the design philosophy, and especially the assumptions adopted in the design, be included in the operational requirements of the system. In order to ensure that this occurs, and to enable system modifications to be as effective as possible, the system designers should ideally remain involved during operation.

b. *System Performance Evaluation and Optimization.* One important aspect of the overall strategy is to periodically evaluate the performance of the system, both the aboveground equipment and subsurface performance. There must be some entity involved in the project that has the responsibility to see that the evaluations are periodically done. Evaluation and optimization is often best performed by an independent review team. Operational data must be available to support the evaluation. Data are collected more frequently during the early, transient stages of operation, and the sampling and monitoring frequencies are reduced as the system moves toward steady-state. Another aspect is to optimize the system to achieve maximum contaminant removal rates at minimum costs as quickly as possible. The strategy generally involves collecting data frequently enough to identify and ensure the continuity of trends. It is important that complete and thorough data sheets are maintained and reviewed in order to track these trends. To support the thorough and consistent evaluation and optimization of these systems, the USACE has prepared checklists meant to guide the users through the process. These checklists have been developed as part of the Remediation System Evaluation (RSE) process developed at the USACE HTRW CX and are available, along with an instruction guide and a sample scope of work, at

<http://www.environmental.usace.army.mil/library/guide/rsechk/rsechk.html>. Checklists are available for guiding the evaluation of subsurface performance of both soil vapor extraction and bioventing. These checklists identify the data needed to perform the evaluation, guide the analysis of the data to evaluate performance, help identify potential problems, and offer alternate technologies that may improve performance or remediation. In addition, checklists are available to guide the evaluation of the performance and maintenance of the aboveground equipment, including blowers, piping, and common offgas treatment devices such as vapor-phase carbon and thermal oxidizers.

c. The initial site model should be periodically updated to include operational data. The updated model can then be used as a basis for further system modification or optimization.

d. The operation strategy may include plans to transition from SVE to BV, or to alter/enhance SVE with ancillary technologies such as air sparging, soil heating, and pneumatic fracturing. Consequently, it will be important to monitor information that would influence the modification of the SVE, or the integration of the SVE system with another technology. For example, for a project that involves BV of fuel oil, it would be useful to track the relative volatility shift in the petroleum hydrocarbon fingerprint of the soil vapors.

e. The O&M plan should contain detailed procedures for monitoring the various physical, chemical, and biological parameters associated with the SVE/BV system. A comprehensive list of these parameters is provided in Table 8-2, although many systems will not need to monitor the entire table.

f. Pulsed venting is a mode of operation for an SVE/BV system whereby the airflow is turned off for some period of time and subsequently turned back on. Reasons for pulsed venting include the following:

(1) Cycling between wells would allow a single blower and treatment system to operate a multiwell system without dividing the total flow rate among the wells. Cycling among wells also helps to avoid the establishment of stagnation points.

(2) In diffusion-limited soils, the concentrations will tend to rebound when the system is shut off. Although the total project duration would increase, the operating time of the SVE/BV system may decrease.

(3) As the more volatile components are removed, it may be advisable to shift the system from SVE to BV. Meeting the oxygen requirements of BV may not require continuous extraction of vapors, or continuous injection of air. During BV, moving air is usually not necessary when soil gas oxygen levels are above a threshold value (refer to paragraphs 3-2*b* and 3-2*c*).

(4) Studies indicate that pulse venting may be more efficient than continuous operation in removing contaminant mass (Oster and Wenck 1988). Brailey and Rog (1989) concluded that pulsed extraction met with mixed results, although generally favorable. The concentration levels did not consistently appear to rebound upon shut off (see Figure 7-1).

Table 8-1. SVE/BV System Operation Strategy and Troubleshooting Guide

Problems	Considerations	Potential Solutions
Vadose zone air flow rates in the area of concern are insufficient or not as predicted	The soil may be less permeable in some locations or there may be preferential flow pathways	Further subsurface investigation Readjust flows Install additional wells Check wells for clogging Check for short-circuiting
Vacuum levels, and therefore pore gas velocities, are spatially inconsistent	There may be preferential flow or heterogeneities	Further subsurface investigation Install additional wells Seal preferential pathways
The VOC concentrations have been reduced in some but not all wells	Treatment may be completed in some areas of the site	Reduce flow to/from wells where remediation appears complete Take some wells offline Check for ongoing sources of contamination
The VOC concentrations remain consistently high despite high mass removal rates	Undiscovered groundwater contamination, free-phase product, or continuing source	Further investigation (particularly for continuous source) Product recovery Groundwater remediation Air sparging
Low concentrations of VOCs are extracted during operation, but high concentrations reappear when system is shut off	Diffusion limitations, water table upwelling, seasonal water table fluctuations, flow short-circuiting due to preferential flow, soils too moist, airflow rates higher than necessary	Dual phase extraction Pulse venting In situ thermal treatment Excavation of "hot spots" and ex-situ soil treatment
Continued high levels of less volatile components	This is likely to occur when SVE is applied to a contaminant mixture with a large range of volatility	Concentrate on bioventing Pulsed venting Soil heating enhancements
A decline in concentration levels has made thermal/catalytic oxidation economically infeasible	"Tailing" of the concentration versus time curve is a common occurrence	Evaluate uncontrolled air emission Switch to activated carbon and/or biofiltration Use other technologies to speed up removal Possibly reduce airflow rates
Poor SVE/BV performance following large rain events	The system is sensitive to the effects of soil moisture on air permeability and aeration	Cap site to reduce infiltration Dual phase (groundwater) recovery Shut off system following major rain events
Unexpectedly high vapor concentrations at or near explosive levels	Free-phase product; Accumulation of methane or other VOCs	Dilute intake air Alter system to be explosion-proof Check for unknown sources of contamination

(5) Pulsed venting also impacts the efficiency of the offgas treatment system. Activated carbon will adsorb organic compounds more efficiently at higher concentrations; therefore, pulsing would tend to reduce carbon usage. Thermal treatment also benefits from higher concentration levels, in that supplemental fuel requirements are reduced. However, a start-up period is necessary to allow these units to reach the proper operating temperature. Thus, fuel consumption could increase if the system is frequently started up and shut down. The amount of operator attention required could also increase.

(6) For BV systems, the airflow rate requirements decrease as the concentrations in the soil and thus the oxygen uptake rate diminish. These systems are typically controlled by monitoring the concentrations of oxygen in the vadose zone and maintaining the concentration above a predetermined level capable of supporting aerobic biological activity (e.g., 5 percent O₂). A sufficient number of monitoring points must be properly placed to determine if vadose zone oxygen levels are being maintained. Sorensen and Sims (1992) suggest that there are advantages to alternating between anaerobic and aerobic conditions during pulsed venting. Anaerobic conditions may allow for beneficial reaction pathways to develop, such as nitrogen fixation. Injection of air and an organic substrate (e.g., methane, propane, etc.) has been demonstrated for in-situ bioremediation of some chlorinated solvents (e.g., TCE), and has been termed cometabolic bioventing. This type of cometabolic process occurs under aerobic conditions; oxygen is the electron acceptor, and the organic substrate is the electron donor. It just so happens that the enzyme used by the bacteria to metabolize the organic substrate also catalyzes breakdown of TCE. The bacteria are not believed to derive energy from TCE degradation.

g. Aboveground soil pile treatment system operation.

(1) OM&M of aboveground soil piles is generally the same as SVE/BV systems.

(2) If bioremediation is to be optimized in the aboveground soil treatment system, maintenance of moisture levels within a predetermined range is important to optimize system performance. If an irrigation system is incorporated into the soil pile treatment system, careful control must be exercised over the frequency and volume of irrigation water applied to the soil pile. In addition, because the movement of air through the soil pile will have a tendency to remove moisture from the pile, some consideration must be given to providing a water-knockout tank of appropriate size, or installation of an automated knockout drainage system.

8-3. Monitoring

Monitoring is performed during the operational phase to evaluate whether the remediation equipment is functioning as designed and whether the remediation is progressing as predicted. The OM&M plan should list the parameters to be monitored and analyzed (see Table 8-2 for guidance), the accuracy and precision required and a schedule for collecting the information. Additional discussions of monitoring methods are described in Chapters 3, 4 and 7.

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Table 8-2. Suggested SVE/BV System Monitoring Checklist**Meteorological**

Precipitation
 Barometric pressure
 Ambient Temperature

Physical Characteristics

Pressure at SVE well(s)
 Pressure at vadose zone monitoring wells/points
 Contaminant concentration at vadose zone monitoring points
 Pneumatic logging (to determine differences in permeability, and contaminant levels, as a function of depth along the well screen)
 Blower inlet vacuum
 Blower outlet pressure
 Vapor temperature at wellhead
 Temperature at blower discharge
 Temperature at treatment effluent
 Wellhead volumetric airflow rate (acmm)
 Blower inlet flow rate (acmm) (upstream from the inlet bleed valve)
 Treatment effluent flow rate (acmm)
 Bleed rate (acmm) (possible to estimate as the difference between airflow rates upstream and downstream from the inlet bleed valve)
 Blower amperage
 Volume of condensate
 Soil moisture content
 Relative humidity in extracted soil vapor
 Groundwater elevation(s) near extraction well(s)
 Degree of upwelling
 Volume of groundwater removed (if any)
 Volume of free product removed (if any)

Chemical Characteristics

Contaminant concentrations at extraction well(s)
 Contaminant concentrations at blower inlet (upstream from the inlet bleed valve)
 Contaminant concentrations at treatment influent
 Contaminant concentrations at treatment midpoint (e.g., between activate carbon vessels)
 Contaminant concentrations in treatment effluent
 Contaminant concentrations in soil gas at monitoring points
 Contaminant concentrations in extracted groundwater
 Contaminant concentrations in condensate
 Contaminant concentrations and oxygen levels in work area (per Site-specific Safety and Health Plan)
 Contaminant concentrations at site perimeter (per regulatory requirements)

Biological Characteristics (see Table 3-1 for analytical methods)

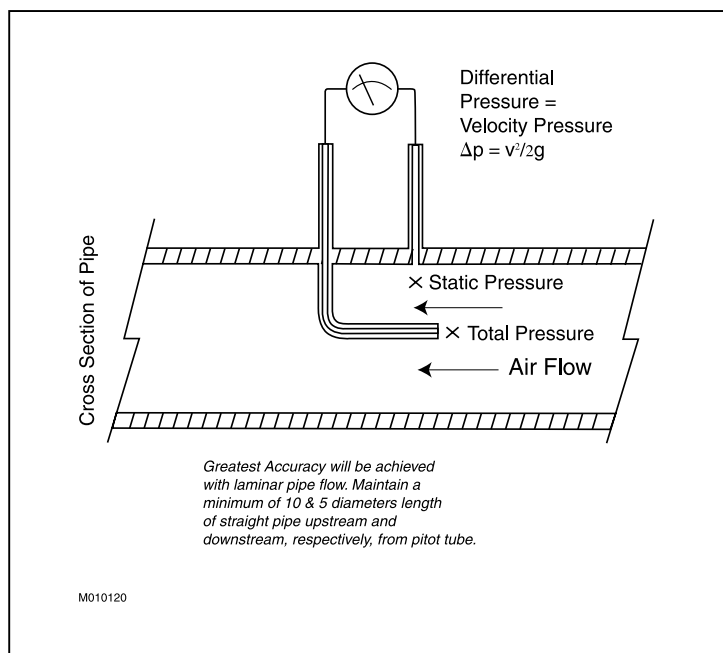
Bacterial enumeration (optional)
 Oxygen concentrations (may be applicable to both bioventing and SVE)
 Carbon dioxide concentrations (may be applicable to both bioventing and SVE)
 Microbial respiration rate (shutdown tests)
 Nutrient concentrations (e.g. nitrogen and phosphorus)
 pH

a. *Physical parameters.*

(1) Vacuum / pressure measurement. Vacuum / pressure readings must be collected and can be measured with manometers, Magnehelic® gauges, or pressure transducers. For critical data collection points like the extraction well(s) and certain monitoring wells, it is suggested that electronic pressure transducers, in conjunction with an automatic data logger, be used to record the data at regular frequent intervals. Over time, the data logger provides a cost-effective alternative to taking manual readings, especially at remote sites. The data can be downloaded via computer modem. However, the data should be verified periodically with manual readings.

(2) Vapor velocity measurement and flow rate calculation. Vapor flow rates must be measured at each extraction and injection well. Flow rates should also be measured at the ambient air inlet and downstream of the ambient air inlet, prior to the blower. The ambient air bleed rate can be double-checked by subtracting the individual extraction well flow rate(s) from the total flow at the blower inlet.

(a) Measurements can be made using a variety of flow meters, including rotameters, hot-wire anemometers, and flowmeters based on a differential pressure reading inside the pipe. Such pressure related flowmeters include venturi meters, orifice plates, averaging pitot and pitot tubes. For most SVE applications, the amount of pressure drop caused by rotameters is not acceptable. Pitot tubes and hot-wire anemometers are typically the most appropriate measuring devices. However, the presence of water in an airstream reduces the accuracy of all flowmeters, and can damage hot-wire anemometers.



(b) Pitot tubes are the most commonly utilized flow measurement in SVE/BV systems. The pitot tube consists of two pressure ports, one perpendicular to flow (static pressure port) and one pointed directly into the flow (stagnation or total pressure port). The differential pressure between these two ports is referred to as the velocity pressure and is a function of velocity. A typical installation of a pitot tube in a small diameter pipe is shown in Figure 8-1.

Figure 8-1 Pitot tube flow measurement schematic

Bernoulli's equation can be used to derive the relationship between velocity and velocity pressure:

$$p_t + h_t + v_t^2 / (2g) = p_s + h_s + v_s^2 / (2g) \quad [\text{Bernoulli's equation.}] \quad (8-1)$$

where the subscript t represents the property at the total pressure port and the subscript s represents the static pressure port.

For SVE/BV systems, $h_t = h_s$ and $v_s = 0$. Therefore:

$$\Delta p = p_s - p_t = v_t^2 / (2g) \quad (8-2)$$

and

$$v = v_t = \sqrt{2g\Delta p} \quad (8-3)$$

In equation 8-3, the differential pressure (or velocity pressure) is the height of fluid (air) and velocity is in length per unit time. However, differential pressure gauges do not have "height of air" scales, but usually have scales in units of mm water, cm water, or mm mercury (Hg). Differential pressure may also be reported as Pascals (ΔP ; force per unit area), which can be related to height of fluid: $\Delta P = \rho_{\text{air}} \times g \times \Delta p$. Rearranging and substituting into equation 8-3:

$$v_t = \sqrt{2\Delta P / \rho_{\text{air}}} \quad (8-4)$$

Height of fluid is related to units for the measuring device (i.e., height of water or height of mercury) by: $\Delta p_{\text{air}} = \Delta p_{\text{md}} \times \rho_{\text{md}} / \rho_{\text{air}}$, where md refers to the units for the measuring device (e.g., mm of water). Therefore:

$$v_t = \sqrt{2g\Delta p_{\text{md}} \frac{\rho_{\text{md}}}{\rho_{\text{air}}}} \quad (8-5)$$

Note again that velocity for the pitot tube is a function of the density of air. Only when $\rho_{\text{air}} = \rho_s = \rho_{\text{standard}}$, where the pressure and temperature at the static pressure port is at standard conditions (i.e., 20°C and 1 atm), can standardized charts be used without a correction for temperature and pressure.

(c) Pitot tubes relate velocity to pressure at the point of the stagnation port, generally placed in the center of the pipe. SVE/BV systems typically use pipe smaller than 150 mm, and measuring the velocity in the pipe at any point other than the center of the pipe is not practical. The velocity at the center of the pipe is the maximum velocity within the pipe and the velocity near the wall of the pipe approaches zero. Best engineering practice for compensating for the non-uniform velocity profile across the cross-section of the pipe is to use an integrated average velocity, often assumed to be 0.9 times the velocity in the center of the pipe. The velocity is used to calculate the volumetric flowrate, Q . Typically the measured flowrate, Q_{measured} , is obtained by assuming that the measurement point is at standard temperature and pressure

conditions, i.e., $\rho_{\text{air}} = \rho_{\text{standard}} = 1.2 \text{ kg/m}^3$. For differential pressure expressed as force per area (e.g., pressure in Pascals or psi):

$$Q_{\text{measured}} = 0.9 \frac{\pi d^2}{4} \sqrt{2\Delta P / \rho_{\text{standard}}} \quad \text{or} \quad (8-6)$$

$$Q_{\text{measured}} = 1.0 d^2 \sqrt{\Delta P / \rho_{\text{standard}}} \quad (8-7)$$

For differential pressure expressed as height of water or height of mercury:

$$Q_{\text{measured}} = 0.9 \frac{\pi d^2}{4} \sqrt{2g\Delta p_{\text{md}} \frac{\rho_{\text{md}}}{\rho_{\text{standard}}}} \quad \text{or} \quad (8-8)$$

$$Q_{\text{measured}} = 1.0 d^2 \sqrt{g\Delta p_{\text{md}} \frac{\rho_{\text{md}}}{\rho_{\text{standard}}}} \quad (8-9)$$

(d) Larger pipe can be fitted with a pitot tube which is constructed of concentric tubes that has the static pressure port located in the outer tube, while the stagnation pressure port is the tip of the inner tube.

(e) Averaging pitot tubes work on the same principle of relating differential pressure within the pipe to air flowrate. Differential pressure is obtained with an averaging pitot tube by measuring pressure at ports in the upstream and downstream sides of a tube (typically 8 to 16 mm diameter) inserted into the pipe perpendicular to flow. There are a series of pressure ports along the tube which pneumatically "average" the differential pressure profile of the cross-section of the pipe. The equations relating this average differential pressure to flowrate are specific to each averaging pitot tube manufacturer. Averaging pitot tubes are more accurate than conventional pitot tubes and can easily be moved from one measurement location to another. Thus, by simply installing measurement ports with compression seals at various locations in an SVE/BV system, flow measurements can be made for the system using a single averaging pitot tube and differential pressure gauge.

(f) It is desirable to report flow rates normalized to a standard temperature and pressure so that flows can be readily compared. Airflow measuring equipment may be calibrated to air at different temperature and pressure than the air flowing through the SVE/BV system. (If airflow measuring equipment is calibrated, it is typically calibrated at standard conditions.) Calibrated gauges must be matched to the correct measuring devices and inside pipe diameter. In some instances, the gauges will have dual scales, with one scale indicating the velocity pressure, and the other indicating the air velocity or flowrate. Direct velocity or flow readings must be corrected to account for the differences between the temperature and pressure of the air being measured, and the temperature and air when the instrument was calibrated. The temperature and pressure (and therefore density) of air in a pipe between an SVE well and blower will be significantly different than the conditions of the air exiting the SVE blower. Therefore, volumetric airflow rate measurements at these two locations are not directly comparable and the measured airflow rates must be corrected for the density difference between the measured conditions and the conditions under which the device was calibrated. Only at the calibrated density, would a flow meter not require correction to obtain a

standardized flow rate or velocity. With the exception of high-end electronic flow meters that can compute an internal correction for air at the measured temperature and pressure (i.e., density), airflow meters do not provide a direct reading (i.e. without needing correction for air density) of standard flow or actual flow. (Standard flow refers to the equivalent flowrate if the air was flowing at standard conditions. Actual flow refers to the flowrate at the temperature and pressure that exists at the point of measurement.)

(g) “Measured” flowrate may be directly read from a gauge that has a scale for direct reading of airflow rates, or may be stored electronically by a data logger in a system with automated data acquisition. The corrected standardized flowrate (Q_{standard}) is equal to the product of the measured flowrate (Q_{measured}) and the square root of the ratio of the density at the calibrated (standard) conditions and the density of the air being measured.

$$Q_{\text{standard}} = Q_{\text{measured}} \sqrt{\frac{\rho_{\text{actual}}}{\rho_{\text{calibrated}}}} \quad (8-10)$$

Applying the ideal gas law to the density ratio provides a more practical correction equation:

$$Q_{\text{standard}} = Q_{\text{measured}} \sqrt{\frac{273 + T_{\text{calibrated}}}{273 + T_{\text{actual}}} \cdot \frac{760 + P_g}{P_{\text{calibrated}}}} \quad (8-11)$$

where P_g is gauge pressure in mm Hg;

T is temperature in °C; and

$P_{\text{calibrated}}$ is the absolute pressure in mm Hg at the calibrated conditions.

Applying the assumption of calibration at standard conditions:

$$Q_{\text{standard}} = Q_{\text{measured}} \sqrt{\frac{293}{273 + T_{\text{actual}}} \cdot \frac{760 + P_g}{760}} \quad (8-12)$$

OR

$$Q_{\text{standard}} = K_{pt} Q_{\text{measured}} \quad (8-13)$$

where K_{pt} is the Correction Factor found in Figure 8-2

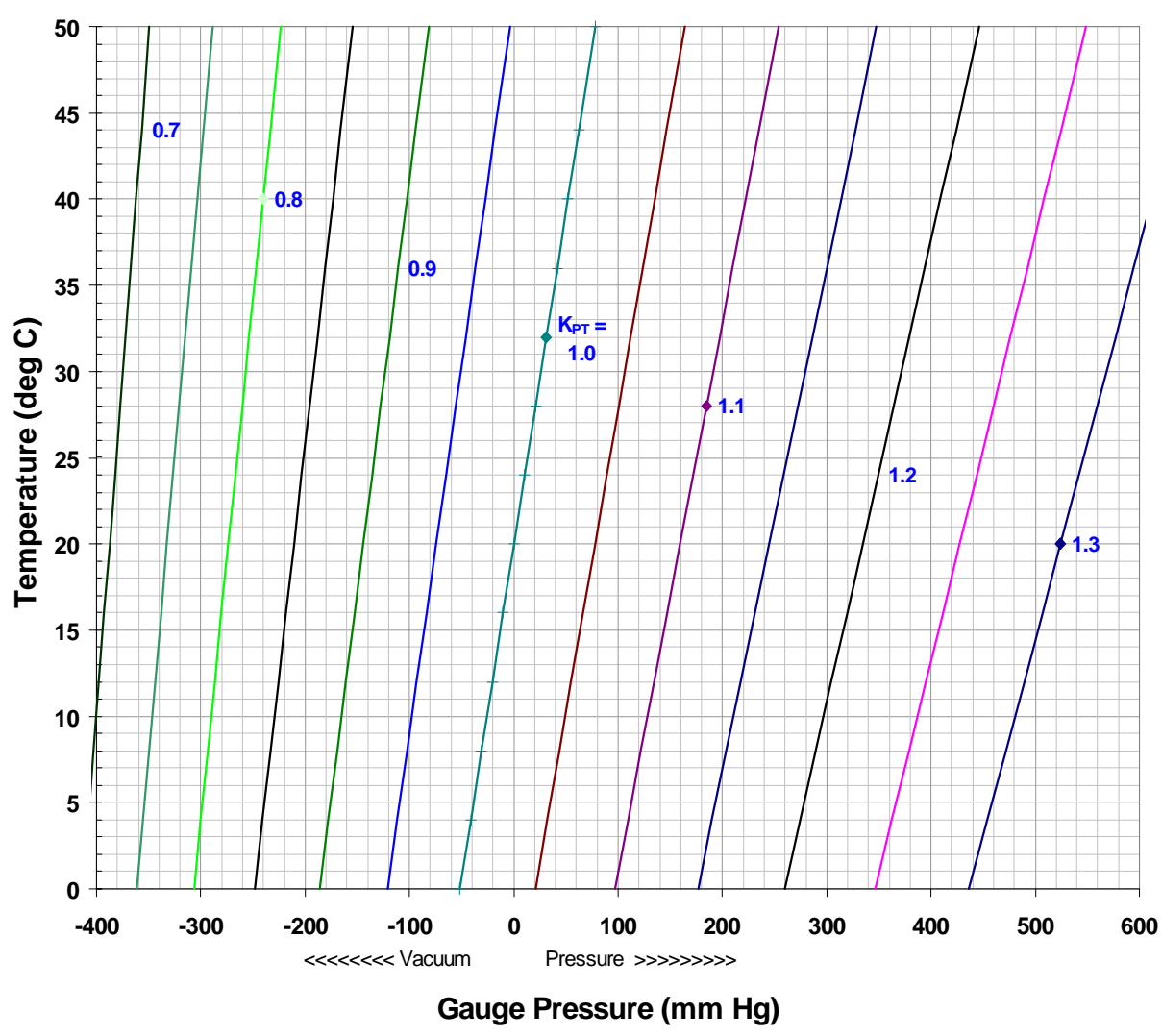


Figure 8-2 Nomograph of flow correction factors (K_{PT}) for converting measured flow (at temperature and pressure different from STP) to standardized flow (i.e., flowrate at standard temperature and pressure)

(h) Equation 8-12 and 8-13 should be used to calculate air emission rates (see Table 7-4), which are based on the extracted flowrate and vapor concentration (which need to be measured at the same time for accuracy). This correction is necessary for such measurements made using rotameters and for volumetric airflow measurements based on a differential pressure measurement, such as pitot tubes, venturi meters and orifice plates. In contrast, hot-wire anemometers measure the mass flux of air flowing past a hot wire and the anemometers' read-outs typically yield velocities as if the flow was under standard temperature and pressure. (Note that if the actual temperature of the air being measured is close to the temperature of the hot wire, e.g. at the outlet of a thermal oxidizer, then this device may not provide an accurate flow measurement.)

(i) An alternate method for calculating Q_{standard} is to calculate Q_{actual} (the actual air flowrate) using the actual temperature and pressure values at the measurement point, and then converting to a standard flow rate as shown below.

$$\rho_{\text{actual}} = \frac{(0.463 P_a)}{(273 + T_{\text{actual}})} \quad (8-14)$$

In the above equation, density units are kg/m^3 , using units of degrees Celsius and mm Hg for temperature and absolute pressure (P_a), respectively. In the following equation, airflow rate is obtained in m^3/min , using units of meters for inside diameter (d), mm Hg for velocity pressure (Δp_{md}), and kg/m^3 for air density (ρ_{actual}).

$$Q_{\text{actual}} = 0.9 \frac{\pi d^2}{4} 978.1 \sqrt{\Delta p_{\text{md}} / \rho_{\text{actual}}} \quad (8-15)$$

Q_{actual} is then converted into a standard flow rate using the following equation. In the following equation, mm Hg and degrees C are used as units for gauge pressure (P_g) and temperature, respectively.

$$Q_{\text{standard}} = Q_{\text{actual}} \frac{293}{273 + T_{\text{actual}}} \cdot \frac{760 + P_g}{760} \quad (8-16)$$

(3) Soil and vapor temperature measurement. Vapor temperatures should be monitored to enable the conversion of flow rates from acmm to scmm, as discussed above, and to ensure accurate determination of the efficiency of the vapor control system. The removal efficiency of activated carbon is affected by temperature. The efficiency may increase or decrease depending on the relative humidity. In addition, piping typically used for SVE/BV applications normally has a temperature limit above which the piping may fail. Soil and soil vapor temperatures would be monitored for a thermally enhanced SVE/BV system. Finally, Connor (1988) predicted that soil temperatures could indicate the level of biodegradation taking place in the contaminated zone(s). Temperatures can be measured with ordinary thermometer probes, temperature gauges, or with electronic thermocouples that provide output to data loggers.

(4) Relative humidity. The relative humidity of the extracted gas should be reduced to protect the blower and to promote the efficiency of the vapor emissions control system (i.e., the adsorptive capacity of

activated carbon is reduced significantly when the relative humidity is greater than 50%). The relative humidity can be monitored to determine the effectiveness of the condensate control system described in paragraph 5-7. Humidity or temperature monitoring can be performed and used to control a humidity reduction / air heating system. The relative humidity of the vapor stream can usually be decreased to about 50% by increasing the temperature by about 20 degrees F.

(5) Water levels. Water levels should be monitored in the area of the extraction well(s) to determine the amount of upwelling that occurs as a result of the applied vacuum. Methods of monitoring groundwater elevations are described in Chapters 4 and 7. Rainfall events can have a significant effect on SVE/BV performance, and should be noted. Local weather stations can often provide compilations of meteorological data.

(6) Air-water separator collection tank (or "moisture separator" or "demister"). The volume of water removed from the vapor stream should be monitored and recorded. The amount of water in the tank can be determined by placing a sight glass on the tank and computing the volume contained. If large volumes are produced and manually or automatically removed and discharged, these volumes should also be recorded.

(7) Blower amperage. Blower amperage should be monitored as a means of determining the load placed on the blower. Excessive amperage may indicate low flow and/or high vacuums across the blower, which could lead to overheating. The amperage can usually be measured at the blower control box using a basic ammeter. The data should be compared with the suggested operating range supplied by the blower manufacturer. Excessive amperage can be resolved by opening the ambient air inlet valve slightly to allow more flow through the blower. This will, however, reduce the vacuum throughout the soil matrix, so the minimum bleed rate should be used to minimize the reduction in the zone of influence. It is important to note that excessive amperage (and thus, excessive strain on the blower) may indicate that the blower is undersized, or that excessive upwelling has occurred in the extraction well(s), or that the well screen(s) have become clogged. These scenarios should be considered and investigated should excessive amperage be found consistently.

(8) Blower and pump run-time and on/off cycles. For blowers designed to operate intermittently, control panels typically include a clock that records cumulative hours of run-time and an odometer-type device that records the number of on/off cycles. This information can prove invaluable should a power outage occur while the unit is unattended, as it enables the operator to determine the time and sometimes the cause of the outage. Similarly, if groundwater and/or NAPL is being pumped to the surface as part of dual recovery system (see paragraph 3-2e), measurement of gallons pumped using a flowmeter can be augmented with pump run-time and on/off cycle data.

b. Chemical. The goals of chemical monitoring are to monitor the effectiveness of the air emission control system and assure that the offgas is within limits; track contaminant mass removal rates; and monitor subsurface chemical conditions.

(1) Prior to start-up of the SVE/BV system, a long-term monitoring plan will have been established and included within the SAP or the O&M manual. The monitoring plan should specify the location of sampling points, frequency of sampling, methods for sampling and analysis, and quality assurance / control requirements (see Chapter 3).

(2) The plan should include more frequent monitoring during system start-up and initial operation. Once the system is optimized, the monitoring frequency and intensity can often be reduced. It may be possible to employ screening methods or analyze for only indicator compounds. Often the chemical constituents do not change over the life of a project; therefore, simpler, less expensive analyses may be sufficient. However, where a mixture of contaminants is present, as in the case of fuel hydrocarbons, more volatile constituents will be depleted first, after which analytical attention may be shifted toward less volatile constituents. See paragraphs 7-4c, and 3-3d for more detail regarding field and laboratory analyses.

(3) System shutdown criteria, which will be discussed in the next chapter, play a strong role in determining the monitoring strategy. Monitoring must primarily demonstrate that the treatment goals are being achieved. For example, if the shutdown criteria require that soil vapor concentrations be reduced to a certain level, the monitoring plan could include provisions for temporarily shutting down the SVE/BV system to allow concentration levels to recover and then measuring VOC concentrations in the soil vapor.

(4) VOCs are monitored to determine the effectiveness of the air emission control system. For activated carbon, VOCs are typically measured before, after, and between carbon canisters. The required frequency of monitoring is determined by conservative carbon usage calculations. Since carbon usage typically decreases during the life of the project, provisions should be made to decrease monitoring frequency. Monitoring is typically performed using a field instrument with less frequent laboratory analysis.

(5) It may be necessary to monitor for compounds other than VOCs. For thermal and catalytic oxidation systems, combustion of halogenated VOCs could create acid fumes; therefore, acid monitors should be employed if halogenated VOCs are suspected.

(6) Chemical and flow rate monitoring of the SVE system influent (or BV system influent, if applicable) should be used to calculate the contaminant mass removal rates from the subsurface. The flowrate and contaminant concentration must be measured at the same time to obtain accurate mass removal rate data. The method for calculating this was presented in Table 7-4 of the previous chapter. This mass removal rate can be compared with an estimate of the initial mass of contaminants in the subsurface. A complete mass balance would also require inclusion of the mass of contaminants that are biodegraded. This latter value may be difficult to assess however. Refer to the discussion in Chapter 4 on in situ respirometry.

(7) Chemical monitoring (i.e., periodically performing soil gas surveys) of the subsurface soil gas will also help gauge the progress of the remediation. Soil gas samples for VOC analysis should be obtained from the effluent of the vacuum blower, from individual extraction wells, and from soil gas probes, air piezometers, or water table monitoring wells. As described in paragraph 7-4c(4), the specific components of the soil gas can be analyzed by gas chromatography or the total amount of VOCs present can be measured with explosivity meters and flame- or photo-ionization detectors. For more frequent (even continuous, if desired) or automated vapor phase chemical monitoring, such instruments can be set up to sample with a air pump and analyze soil gas on a fixed schedule and then transmit the data over a telemonitoring system or store the results using a datalogger. Monitoring the concentrations of oxygen, carbon dioxide, and sometimes methane helps establish the level of biological activity in the subsurface (see paragraph 8-3c).

(8) Chemical analysis of accumulated condensate from the moisture separator is usually required for discharge or disposal purposes. If the volume of condensate is significant, the concentrations can be used to calculate the amount of contaminant mass being removed via the dissolved phase.

c. Biological. Biological degradation (biodegradation) of both volatile and non-volatile contamination is an important process in soil vapor extraction and is a critical process for bioventing. Monitoring of biological activity before and during bioventing can be accomplished by several means in addition to observing changes in the contaminant concentrations themselves (see Chapter 3 for information on microbial activity assays).

(1) Microbiological tests can be used to screen for conditions which may be toxic to microorganisms. Toxic conditions could, for example, be caused by excessive contaminant concentrations, heavy metals, or other environmental factors. Changes in the toxicity of soil water extracts can signal when toxic conditions are alleviated, such as through pretreatment of soil prior to construction of an aboveground pile. The Microtox™ test is one commonly used and is a relatively inexpensive assay which involves exposing a specific strain of luminescent bacteria to a sample and then measuring the light output of the bacteria after exposure under standard, reproducible conditions. The light output is compared with that of a control, and a difference in light output is attributed to the degree of toxicity of the sample. The more the luminescent bacteria are challenged by the presence of toxins, the lower is their light output.

(2) Soil Gas Composition. Concentrations of oxygen and carbon dioxide in the soil gas are routinely monitored during BV operations using portable gas meters; and should be monitored at SVE sites when the contaminants are amenable to biodegradation. It is important that portable meters have the capability to measure wide ranges of concentrations with adequate sensitivity. If carbon dioxide concentrations exceed the range of the meter, the sample can be diluted with ambient air. Significant deviations from ambient conditions (dry atmospheric air contains approximately 20.9 percent oxygen and 0.03 percent carbon dioxide) in soil gas are possible in soil undergoing “natural” biodegradation. Prior to BV at one site, 0 percent oxygen and 26.4 percent carbon dioxide were measured in soil gas (Hinchee, Ong, and Hoeppel 1991). Such low oxygen and high carbon dioxide concentrations provide an indication of aerobic biological activity. High concentrations of methane, which can also be measured with portable gas meters, have been observed and can be attributed to anaerobic biodegradation. If bioventing is delivering sufficient air to the subsurface, the soil gas composition should be closer to atmospheric conditions. Aerobic activity should also be stimulated and anaerobic reaction should cease producing methane, although in low permeability strata, methane may continue to be produced.

(3) Respiration rate determinations. One way to evaluate in-situ biodegradation and bioventing in the vadose zone is to periodically perform an in-situ respiration test. This is done by first measuring oxygen and carbon dioxide concentrations in soil gas extracted from extraction and monitoring wells in the remediation zone during or immediately after many weeks of bioventing. The bioventing is then stopped and these gas concentrations are measured over time. Typically, if contamination or other organic matter still exists, oxygen is consumed and carbon dioxide is produced. If one assumes a stoichiometric relationship between oxygen consumption or carbon dioxide generation and contaminant biodegradation, contaminant biodegradation and removal rates can be estimated. Care should be taken, however, to account for other abiotic sources and sinks such as oxygen consumption (e.g., in oxidizing native organic matter or ferrous iron) or diffusion and carbonate cycling since the subsurface is not a closed system. Having fewer abiotic sources and sinks, oxygen is generally recommended over carbon dioxide for determining biodegradation rates (Ong et al. 1991). By performing these respiration rate determinations periodically (quarterly to annually depending on the expected rate of change) and observing changing rates,

the progress of the bioventing and contamination reduction can be evaluated. The observed rates could be compared to rates that may have been measured in laboratory respiration tests. This information can also be used to optimize BV flow rates which deliver oxygen to the soil. Sayles et al. (1992) suggest maintaining oxygen concentrations above 5 percent to avoid oxygen limitation of microbial activity.

d. Aboveground soil pile treatment system monitoring.

The aboveground soil pile treatment system should require a minimal level of system monitoring. Methods of system monitoring are typically consistent with measures implemented for SVE/BV treatment systems.

(1) Soil gas monitoring. Permanent soil gas probes used in SVE/BV can be used in soil piles. However, they are usually hand-installed during or after soil pile construction. Care must be taken to assure that tubing/piping to soil gas probes do not serve as pathways of preferential airflow. Levels of oxygen, carbon dioxide, and total petroleum hydrocarbons are typically monitored under two regimes:

Concentrations as a function of time after blower shutdown.

Concentrations as a function of time after blower start-up.

The measurement regimes will allow assessment of biological activity, airflow efficiencies, advection/diffusion limits, etc. Respirometry data reduction is performed in a manner identical to BV data reduction.

(2) Soil sample collection and analyses. Soil samples may be taken periodically to assess progress toward a soil-concentration based cleanup goal. Soil sample collection is typically conducted using hand-augering tools and hand-driven sampling devices. Once samples are retrieved, some effort should be made to backfill hand-borings in such a manner that preferential airflow pathways are not created. Chemical analyses are performed in the same manner as for in situ SVE/BV. Note that heterogeneous distribution of contaminants in soil may obfuscate expected trends in the data. Statistical analyses of sets of samples may be necessary to identify trends in soil concentration data (see Chapter 9).

8-4. Venting Well Maintenance

a. The maintenance of a venting well includes measures to ensure that the vapor being drawn through the wells is unimpeded and contributed from the entire zone of influence for which the well was designed. This implies that the venting well must be kept airtight and free of debris or biological or chemical buildup which could clog the well screen.

b. One of the leading causes of vapor short-circuiting is a dried-out, cracked casing seal, which is fairly common in certain types of grout when subjected to a vacuum. After a period of time, all the moisture is evacuated from the grout, forming cracks which allow preferential vapor flow down the sides of the casing. As the cracks progress and the grout shrinks, vibrations of the well casing tend to intensify the damage. This situation can be detected, however, by carefully pressurizing the well (avoid over-pressurization) and checking for leaks using soap solution. An alternative method is to simply pour 3 to 4 liters of water onto the grout around the well casing and observe the time it takes for the water to permeate the grout. A severely damaged seal will absorb the water in a matter of minutes, while a good seal should be capable of holding the water for upwards of an hour. If the seal is slightly damaged, an

additional layer of grout could be placed over the existing layer (with the extraction system shut off) in order to seal the cracks. However, if the damage is significant, the well must be replaced.

8-5. Vapor Collection System OM&M Considerations

a. OM&M design considerations. Operations and maintenance requirements should be taken into account early in the design of the SVE/BV system. There are, however, requirements for maintaining equipment that cannot be designed away. Operating a unit can be completely automatic (more expensive), semi-automatic with operator interface, or manual. The system design will include trade-offs between capital costs and OM&M costs. Needs for operator involvement depend on the size of the unit, the importance of keeping the unit running full time, the phase of cleanup (i.e. start-up operations or the final stages of cleanup), and other factors.

b. Unit size. The size of a unit may influence the amount of OM&M effort required. For example, one large carbon bed may not require changing for months but may be less efficient than smaller units requiring changing more often.

c. Explosive and nonexplosive vapors. A properly designed system will minimize fugitive vapor emissions. In the case of approved releases of VOCs directly to the atmosphere, release points should be located away from sensitive receptors and potential sources of ignition. Explosion hazards should be considered relative to other aspects of the SVE/BV systems as well.

(1) Some vacuum pumps generate high discharge temperatures. If these units push high-temperature gases into carbon beds, there is the possibility of spontaneous combustion that can produce even higher temperatures, thereby propagating the combustion. Starting an internal fire fanned by a vacuum pump or blower is possible. If the concentration of organic vapors falls between the upper and lower explosive limits, the possibility of explosion exists.

(2) Vacuum pumps have internal clearances that affect efficiency. If a rotary lobe vacuum pump is poorly maintained and has a bearing or lobe failure, the unit may be damaged beyond repair. Also there is greater potential for a poorly maintained unit to create a fire hazard, especially if high concentrations of organics are being extracted.

(3) Thermal oxidizers by nature operate at high temperatures. Again, a flame arrestor should be included to preclude the possibility of fires.

(4) Carbon canisters can sometimes contain high concentrations of VOCs that can leak into the surrounding atmosphere during the changing of these units. The equipment should include valves to isolate the liquids and fumes before piping, hoses, or ducts are disconnected, as well as provision for fire protection/suppression (see paragraph 5-12*b*).

(5) To avoid static electricity buildup, all equipment should be grounded as should the building and other items inside the building where the process equipment is installed.

(6) The National Fire Protection Association (NFPA) prepared a guide on hazardous materials (1994) which includes data on flashpoint, specific gravity, water solubility, hazard identification, and boiling point

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for flammable liquids, gases, and solids. Material safety data sheets assembled for a site will contain information on the physical and chemical properties for contaminants of concern. Fire hazard data are also included that identify combustibility, flammability, and explosivity of the compounds.

(7) Automatic shutdown systems should be included in any system that handles flammable/explosive fluids. If temperatures approach hazardous levels, warnings should be initiated and systems shut down if dangerous conditions are reached. Fire protection systems, such as sprinklers and blast doors should back up these shutoff systems.

d. Operator training. Formal operator training is needed to adequately prepare site operators to safely and effectively operate and maintain the SVE/BV equipment. Training should include classroom and hands-on training.

8-6. System Operation Schedule

The operation time of an SVE/BV system may be partly based on offgas VOC concentrations. When VOC concentrations in the offgas fall to inefficiently low levels, the system may be turned off for a period of time so that the VOCs can diffuse into soil pores participating in advective transport. The diffusion rate is dependent upon the diffusivity of the VOC constituents, moisture content, and a variety of other subsurface conditions (refer to paragraph 8-2). Table 8-3 is a generic checklist that should be kept at the site for routine O&M checks.

Table 8-3. Routine Maintenance Items

Periodically drain the water that has accumulated within the PVC pipe header lines.
Monitor the inlet and outlet vacuum. Adjust ambient air intake and manifold valves as needed.
Monitor the outlet temperature of the blower. If the blower temperature approaches the upper limit (as indicated in manufacturer's literature), decrease the vacuum or troubleshoot the unit.
Verify that the air water separator and transfer pump are working properly.
Check daily calibrations of the VOC analyzer. Make any corrections to the analyzer response.
Monitor gas cylinders for proper operating pressures and levels.
Approximately every 500 hours (or per manufacturer's recommendations), re-grease blower assembly per manual.
Approximately every 1500 hours, change oil in blower assembly, adding oil suitable to ambient conditions for the next quarter.
Monitor pressure drop across filters, and periodically clean or replace particulate filters.

8-7. Recordkeeping

A formal data management system is vital to efficient operation of the SVE/BV system. Vacuums/pressures, flow rates, temperatures, and other operating parameters need to be monitored and recorded. Information regarding sample location, date and time of collection, laboratory, test method, analytical results, detection limits, and associated quality control samples must be tracked. For large SVE/BV systems, a computerized data management system is suggested. Recently, all member agencies of the Federal Remediation Technologies Roundtable (including all branches of the DOD) have endorsed standardized collection and reporting of remediation performance and cost (USEPA 1995).

8-8. System Evaluation/Modifications/Optimization

To cost-effectively remediate sites, an increasingly important aspect of operating a SVE or bioventing system is optimization of the remedial processes. In their guide to system optimization “Draft Final Remedial Process Optimization Handbook”, AFCEE, Brooks AFB, TX, (AFCEE, 1999), AFCEE reports that the DOD alone will spend over \$1 billion per year on OM&M. AFCEE recommends performing Remedial Process Optimization (RPO) evaluations at least once per year at some degree of detail. Depending on the complexity of the remediation system, the evaluation/optimization team should involve hydrogeologists, engineers, chemists, risk assessors and regulatory specialists to complete this evaluation. In addition to increasing the speed of remediation, optimization can also lead to cost savings (for example, by changing from expensive catalytic oxidation to activated carbon adsorption or biofiltration for vapor treatment).

AFCEE recommends review of the SVE from three perspectives:

1. Evaluation and optimization of the operation of the existing system with the goal of maximizing the rate of contaminant mass removal to achieve the greatest reductions in contaminant concentrations and minimize operating costs.
2. Re-evaluation of the system components (e.g., wells, blowers, offgas treatment system) to determine if changing or adding to the system will increase performance or to determine whether a wholly new technology is necessary.
3. Re-examination of the remedial goals in light of new regulations or risk evaluations are applicable.

a. Evaluation and optimization of the existing remediation system should be performed to accomplish the following goals: to maximize the removal rate of contaminant mass, to reduce the costs of system operation, and to reduce the amount of time it will take for the system to achieve cleanup criteria (for more information, see the Remediation System Evaluation checklists, at <http://www.environmental.usace.army.mil/library/guide/rsechk/rsechk.html>.) This evaluation should include confirming that any discharge concentration requirements are being met. The OM&M costs for achieving this degree of remedial progress should be compiled and reviewed. Often, one of the largest costs of an existing remediation system is the monitoring program. The monitoring plan should be evaluated for the potential of reducing monitoring costs or getting better data for the same costs. (However, it is important to emphasize that acquiring system performance data, such as flow rates and concentrations from individual wells is relatively inexpensive and very helpful for continuing system optimization. Most cost savings occur in reducing compliance monitoring, such as groundwater sampling by USEPA SW-846 methods.) Most system modifications are made because the soil vapor flow is not occurring where it is needed or the equipment is not functioning as designed (equipment problems will be discussed in the next section on troubleshooting). Some examples of common operational modifications that can be made to an existing system are described below.

(1) Optimization is often desirable after much of the contamination has been removed and local “hot spots” remain. At this point, subsurface VOC concentrations in soil and soil vapor at individual wells should be checked to determine which wells are responsible for most of the mass removal. Wells in areas that do not yield much mass can be taken “off-line” or operated to concentrate airflow on the more contaminated areas. Care must be taken during this analysis to ensure that adequate capture zones are maintained at sites where vapor emissions to the surface are important.

(2) One problem encountered in shallow systems (less than 1.5 meters to the water table) or in soils with high proportions of silts and clays is the possibility of excess moisture in the treatment zone (due to upwelling) and subsequent introduction of water into the vacuum system. A cyclonic separator may be overloaded very quickly if water is entrained in the air stream which can in turn infuse vapor phase activated carbon with water, substantially lowering its sorptive capacity. This process often causes excessive system “down-times” and offgas treatment costs. This problem can be mitigated by improving moisture separation and/or actively pumping groundwater to counteract the upwelling in situ.

(3) A related problem is the requirement for large vacuums due to tight soils or a shallow water table. If the vacuum generated at the pump is greater than the elevation head of the water table, the pump will sometimes draw the water to the surface whether the site is flooded or not. Liquid-ring vacuum pumps capable of drawing 635 mm of mercury vacuum will pump water from depths of at least 6 meters.

b. The second category of optimization is re-evaluating the existing remediation system and, if warranted, modifying it by adding or replacing SVE wells for example, or changing the vacuum blower to increase flow and applied vacuum, or changing a SVE system to a bioventing system. If the soil gas flows too directly from the surface to the SVE wells’ screens without traveling horizontally enough to encounter all contaminated soil, a lower permeability surface cover may need to be installed. This re-evaluation should also include the assumed contamination situation which may differ based on information gathered during the on-going remediation.

8-9. Troubleshooting

There are several mechanical components to an SVE/BV system which are subject to operating problems. Many of these become apparent at start-up, but others appear later if the system is not properly maintained. These parts of the system will be considered in order of flow. Troubleshooting guides are also provided in Table 8-1, and the Remediation System Evaluation checklists, at <http://www.environmental.usace.army.mil/library/guide/rsechk/rsechk.html>.

a. Filters. The air from the well is usually filtered through two stages to prevent damage to the vacuum unit. Problems associated with the lead filter, which is often a cyclonic system to remove soil and water droplets, are primarily related to plugging of the drain line with mud. The second filter is usually a fine filter, which should be checked daily during initial SVE (and BV, if applicable) system operation to make sure it is not blocked.

b. Vacuum pump. As long as the pump is properly lubricated and the filters are working properly, the vacuum pump should not experience operating problems. Performance checks against the pump curve should be conducted regularly during start-up to make sure airflow and vacuum levels meet expectations. Also the amount of current (amps) drawn by the blower should be measured.

c. Air treatment. The operating problems associated with carbon systems are usually minimal as long as the air is filtered and dehumidified. The carbon exhaust should be monitored periodically to ensure that the air being discharged meets the requirements of the air permit. If a thermal oxidation system is used, the system itself will have maintenance needs, and again the exhaust will need monitoring. In operating incinerator units, care must be taken that the VOC concentration in the incoming stream from the wells is factored into the burner operation, and as the concentration is reduced, the incinerator is adjusted accordingly. Burners typically are self-regulating within a limited range of fuel-to-air ratios; the range is

termed a turn-down ratio. A typical turn-down ratio may be 20 to 1. The burner will require readjustment if, due to a decrease in influent air concentration, the change in fuel-to-air ratio exceeds the turn-down ratio. Refer to USACE guidance documents on offgas treatment methods.

d. Control systems. Operating problems with control systems may occur due to malfunction of electrical components (which usually requires a service call by the equipment supplier), damage to buried wiring by burrowing rodents, or by exposure of components to weather extremes for which they were not designed. Enclosing the control systems in a heated (or cooled) shed will prevent damage from exposure to temperature extremes.

8-10. OM&M Protocols

Throughout the course of the remediation, the system O&M manual will consistently be one of the most useful documents associated with the project. The O&M manual should contain detailed descriptions of any and all activities pertaining to the SVE/BV system that could potentially take place. The manual should be written so that a technician unfamiliar with the site could follow the instructions and perform any OM&M activity properly. Since design changes are common during system installation, commissioning and start-up, the O&M manual and as-built drawings should be completed at this time; and updated as changes are made.

a. The following is a general outline of the topics to be covered in an O&M manual for a basic SVE system:

I. Introduction

- A. Purpose of the O&M Manual
- B. Objectives of the Remediation System
- C. Description of Facilities
- D. Project Organization
- E. Record-Keeping

II. Description of System Components (*includes As-Built Diagrams*)

- A. Well Configuration and Construction Detail
- B. System Piping and Instrumentation
- C. Vapor Collection System
- D. Vapor Pretreatment System
- E. Vapor Treatment System

F. Ancillary Equipment

G. Controls

III. System O&M

A. Start-Up

B. Routine Operating Procedures

C. Troubleshooting

D. Changeover from SVE to BV (if applicable)

IV. Contingency Plan

A. Mechanical Contingencies

B. System Modifications

C. Criteria for Triggering Corrective Action

V. System Maintenance

A. Weekly/Monthly/Quarterly Inspections (*including log sheets*)

B. Routine Maintenance Procedures (*including log sheets*)

C. Consumables and Spare Parts Inventory

VI. Monitoring, Sampling, Analysis, and Reporting Documentation

A. Remediation Goals

B. Discharge Limits

C. Sampling and Analysis Schedule

D. Reporting

E. Quality Assurance / Quality Control

Appendix A - Health and Safety Plan

Appendix B - Standard Operating Procedures

Air Sampling

Water Sampling

Water Level Measurement

b. This outline is intended for a basic SVE system only. Similar procedures for bioventing and other technology options (see paragraph 3-2) should be included as necessary.

c. While the contents of most O&M manuals are by nature highly site-specific and very detailed, an example section on weekly inspections is presented below to inform the reader of the types of information that should be included in the O&M manual. The contents of the example section have been generalized and abridged to maintain conciseness. Much more detail would be included in an actual manual.